Der Anschnitt, Beih. 42, S. 31 – 46, 2019

Thomas Koch Waldner

Bronze Age copper production in Kitzbühel, Tyrol

ABSTRACT: *In the Kitzbühel mining district there are several rich chalcopyrite deposits, which have been used for mining since the 2nd millennium BC. From Pongau via Pinzgau, miners and with them the "Eastern Alpine copper technology" reached the Tyrolean Leukental during the Middle Bronze Age. The quality and frequency of the deposits led to the development of one of the most important alpine copper production centres of the late Bronze Age in this region. Thanks to the numerous finds, the working chain of prehistoric mining and metallurgy can be reconstructed. In the course of mining activities in the 19th century several prehistoric underground mines were discovered, which still contained numerous finds. Today, these sites are no longer accessible, which is why underground mining can only be reconstructed on the basis of finds, descriptions of findings and supra regional comparisons. The second and third link in the production chain ("chaîne opératoire") can be thoroughly investigated and reconstructed in detail thanks to the vast ore-processing heaps in the Kelchalm district near Aurach and more than 50 smelting sites between Kitzbühel and Jochberg. The way of working, the tools and the facilities show clear parallels to the mining regions to the east near Viehhofen and the Mitterberg area in Salzburg. On the basis of the current dating results, the geological-mineralogical situation and the geographical location of the Kitzbühel mining region, it can be assumed that the "Eastern Alpine copper technology" was transferred from here to the west in the Lower Inn Valley. The significant development was that chalcopyrite-oriented technologies were adapted to fahlore deposits, ushering in a new era of prehistoric copper mining.*

KEYWORDS: MINING, ORE-PROCESSING, SMELTING, COPPER, SLAG, CHALCOPYRITE, DEPOSITS.

Due to numerous Bronze Age traces of mining and metallurgy, the southern Leuken Valley from the Pass Thurn over Jochberg and Aurach to Kitzbühel is one of the most important prehistoric mining landscapes of the Alps. The abundance of sites with archaeological evidence of mining shows that this area was a supra regionally important production area for copper more than three thousand years ago. Essentially, this central mining area has significantly influenced the technological and economic development of Central Europe, the Alpine landscape and the society of the Bronze Age.

History of research

Favored by the historical and modern mining industry, which came upon many traces of prehistoric mining in various Austrian regions, these relics began to be documented relatively early. This resulted in the fact that already in the beginning of prehistoric research in Austria in the 19th century, there was a considerably strong awareness of the importance of mining archaeological monuments. Owing to the extraordinary findings and reports, the academic focus was put on the salt mines of Hallstatt and Dürrnberg as well as the copper mining areas of the Mitterberg region near Mühlbach/Bischofshofen and in the Kitzbühel region.

Matthäus Much, a pioneer of mining research, was the first prehistorian to collect and document the findings of prehistoric mining in the Kitzbühel area in the 19th century (Much, 1879; 1893; 1902). However, the systematic exploration began in the 1930s and was performed by the archaeologist Richard Pittioni and the mining engineer Ernst Preuschen. Their investigations of the ore-processing heaps of the Kelchalm district near Aurach between the 1930s and the 1950s proved particularly decisive. The findings and results from the excavation campaigns were presented in three extensive reports (Preuschen & Pittioni, 1937; 1954; Pittioni, 1947), which led to the fact that the heaps in the Kelchalm area are among the best explored Bronze Age mining relics of the Alps. Following these investigations, Pittioni and Preuschen put their main emphasis on the legacy of prehistoric copper smelting. Throughout the 1970s, they localized and investigated around 40 prehistoric smelting sites by means of prospecting and collecting information from the local population (Preuschen & Pittioni, 1955; Pittioni, 1968).

After Pittioni had retired, it was only in the 1990s that individual prospections and excavations were re-initiated and further smelting sites were localized. In the years 1993 and 1995 smelting facilities – a two-phase roasting bed and four shaft furnaces – were documented for the first time in the area of the Wurzhöhe west of Jochberg (Goldenberg, 2004).

Lastly, the Austrian Academy of Sciences facilitated several years of systematic research on prehistoric mining in the Kitzbühel region under the direction of the author. The funded project was located at the University of Innsbruck and was integrated into the research center "HiMAT". It included targeted prospecting and excavation campaigns as well as reassessment of preceding research findings and results (Koch Waldner & Goldenberg, 2012; Koch Waldner, 2013a; Koch Waldner, 2017).

Expansion of the eastern alpine copper technology taking into account types of mineral deposits

The mining region of Kitzbühel is largely characterized by deposits that are dominated by chalcopyrite located in slate as wall rock. Two conditions correlate with those of the mining regions east of Kitzbühel: the geological conditions, as well as the type of deposit in which chalcopyrite occurs predominantly in quartz, but also in iron carbonate and slate. In addition, there are rich fahlore deposits, which in several cases show similar geological conditions to those in the Lower Inn Valley[1].

From the late Early Bronze Age (17th century BC) to the emerging Late Bronze Age (13th century BC), only chalcopyrite was used as copper ore in the Eastern Alps and beyond (Pernicka & Lutz, 2015), where mainly the previously described type of deposits was exploited. From this type of chalcopyrite-oriented mining industry, a supra regional techno-complex, the so-called eastern alpine copper technology, developed in the area of the western Greywacke zone. According to current research, the techno-complex initially spread along the entire Greywacke zone, from Tyrol/Salzburg to Lower Austria and eventually beyond to South Tyrol, Trentino and Graubünden (Stöllner, 2009; 2015). In the course of the late Bronze Age (13th–8th century BC), fahlore was extracted and smelted, whereby the chalcopyrite technologies were adapted to the fahlore deposits.

Over the Kitzbühel Alps, the miners and their technologies eventually reached the Inn Valley, as well as the east alpine Kristallin and finally the Swiss Alps. To the east, the mining and metallurgical industry crossed the Eisenerz Alps to the east end of the Alps in Lower Austria. Following the deposits to the south, the knowledge about copper production from sulphidic ores spread over East and South Tyrol up to the southern edge of the Alps in today's Trentino.

In accordance with this expansion model, the miners and metallurgical workers reached the Kitzbühel region across the Pinzgau during the Middle Bronze Age. In the southern Leukental and the adjoining valleys, they encountered a large number of chalcopyrite deposits. This turned the region into one of the most important Bronze Age copper producers in Central Europe.

The chalcopyrite dominated deposits at Jochberg and Aurach belong to the copper-iron ore district of the Glemmtal-Unit and are essentially comparable to the deposits at the Bronze Age mining area of Viehhofen. To the north and west of Aurach the boundary of this deposit area extends to the "Hochhörndler Schuppenzone". Along the Brixen Valley, at the altitude of Kitzbühel, there is the fahlore/chalcopyrite ore region of the Wildseeloder-Unit (Heinisch et al., 2015). It was probably in this region that Bronze Age prospectors, for the first time, encountered a type of chalcopyrite that was strongly mixed with fahlore and with different geological conditions.

Besides shale, the copper deposits in this area are often connected to limestone breccia and dolomite. Due to the different geology and mineralization of the districts in the Wildseeloder-Unit and the Hochhörndler Schuppenzone, the historic Kitzbühel mining district was divided into three zones – a northern, a central and a southern one (Pošepný, 1880). The majority of the prehistoric mining traces can be found in the southern zone or the Glemmtal-Unit near Jochberg and Aurach. In addition to numerous smelting sites, especially at Jochberg, the ore-processing heaps as well as the subterranean Bronze Age mining in the Kelchalm district belong to this zone. It is important to emphasize that up until today, the research of this area only offers evidence for the use of chalcopyrite.

Further evidence of Bronze Age ore mining and copper smelting are found in the middle zone, which includes the area of the Wildseeloder-Unit and the Hochhörndler-Schuppen Zone. Prehistoric mining traces were found in the form of underground mining sites in the Schattberg district, as well as through evidence of ore-processing on the Götschen in the Brixen Valley and smelting sites near Kitzbühel and Aurach.

Given that the Kitzbühel mining region features both the chalcopyrite used in the Middle and Late Bronze Age as well as the fahlore used in the course of the Late Bronze and Early Iron Age, this region plays a special role considering the spread of prehistoric copper mining. The prospectors of the Bronze Age probably recognized quite soon that the area west of Kitzbühel – the Lower Inn Valley – shows a decrease in the share of the much

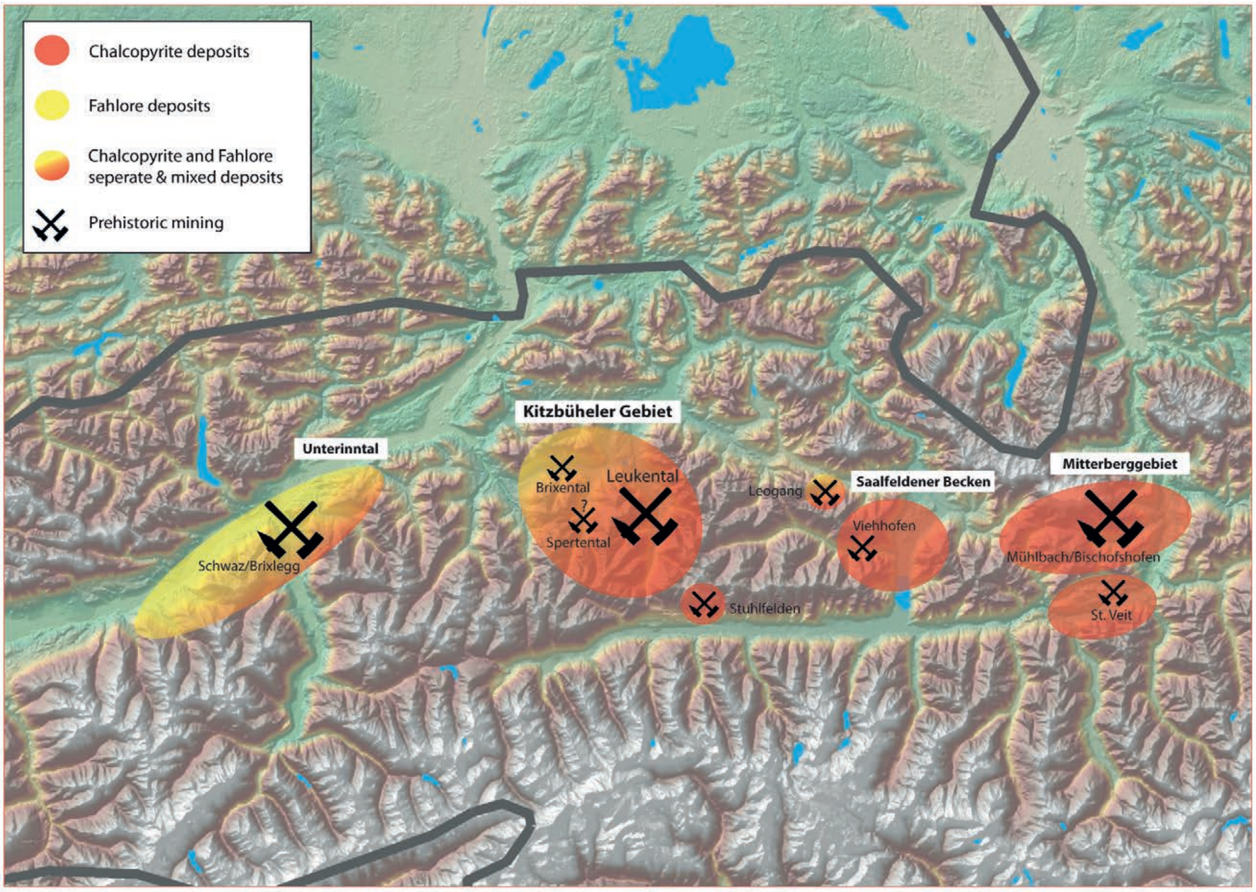

Fig. 1: Prehistoric copper mining regions in the western Greywacke zone (according to Koch Waldner 2017).

sought-after chalcopyrite. However, the considerable abundance of copper ore does not break off in the west, since chalcopyrite is replaced by fahlore. Given the chronological and geographic location of the Kitzbühel mining region – between the older chalcopyrite districts of Salzburg and the younger fahlore districts in the Tyrolean Lower Inn Valley – it seems probable that the miners and metallurgical workers of the eastern alpine copper technology – after an experimental phase with fahlore – started to explore fahlore deposits in the areas bordering on the west (Koch Waldner, 2017).

Traces of the prehistoric mining and metallurgy in the Kitzbühel region

The largest concentration of mining archaeological sites can be found in the southern Leuken Valley in the municipalities of Jochberg, Aurach and Kitzbühel. One must keep in mind, however, that the prospections of the 20th century exclusively focused on this part of the region. The mining relics that are situated outside the valley demonstrate that the prehistoric mining industry must have stretched beyond Leuken Valley. Up until today, however, these areas were not the focus of scientific research. These include the prehistoric ore-processing heaps on the Götschen in the Brixen Valley (Neuninger et al., 1970) as well as alleged Bronze Age mining traces on the Brunnalpe in the Sperten Valley.

This region was given particular attention due to the processing heaps in the Kelchalm district, wich are some of the most impressive surface relics of prehistoric mining in the Alpine region.

Thanks to the localization of numerous smelting sites by Pittioni as well as ambitious locals such as the former Jochberg village chronologist Georg Jöchl, the region was defined as a large-scale mining landscape. After further prospecting in the past years by employees of the Research Center HiMAT of the University of Innsbruck 52 smelting sites are known now.

Prehistoric traces as deposit indicator for historical mining industry

Prehistoric mining traces served as historical indicators for mining deposits. This has often led to an overprinting of Bronze Age pings and heaps through historical mining and processing activities. As a consequence, depressions and heaps of the Bronze Age could be clearly identified

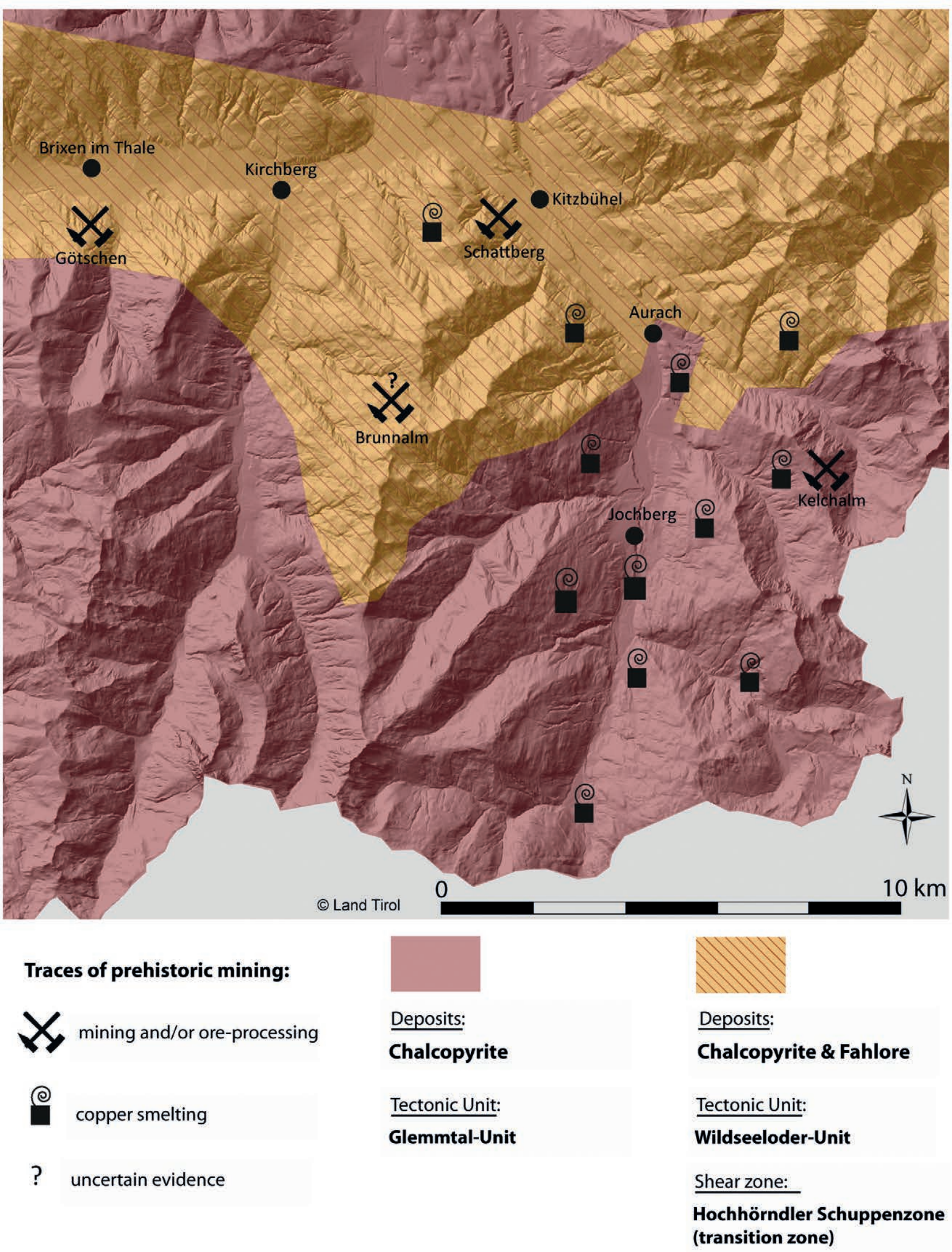

Fig. 2: Geological conditions and traces of prehistoric mining in the region of Kitzbühel.

solely in a few mining districts. Particularly noteworthy is the fact that the deposit of the Kelchalm district was rediscovered in the 18th century due to prehistoric heaps and depressions. The k.k. deposit researcher Franz Pošepný reported:

„Durch die 1751 gemachte Entdeckung des Erzvorkommens auf der Wildalpe, ist man auf die am Gebirgsrücken zwischen dem Aurach- und Wiesenegger-Thale befindlichen Pingen und Halden aufmerksam gemacht worden, was 1769 zur Begründung des Kelchalpner, gegenwärtig productivsten Kupferbergbaues des Kitzbühler Districtes führte.“ (Pošepný, 1880).

"The 1751 discovery of ore deposits on the Wildalpe to draw attention to the depressions and heaps on the mountain range between the Aurach and Wiesenegger valley, which in 1769 led to the establishment of a mine at Kelchalpe, the most productive copper mine in the Kitzbühel district".

Smelting sites as indirect indicators for ore mining

The distribution of smelting sites from the Sinnwell district near Kitzbühel in the north up to the valley end at the Pass Thurn in the south serves as indication that Bronze Age miners prospected the entire Kitzbühel region. This also suggests that they made use of most of the exploitable copper deposits they could discover. Already Pittioni was convinced that the smelting sites to the west of Jochberg were supplied with the ores of the Wurzhöhe (Pittioni, 1976). Considering the spatial proximity of the smelting sites to the copper deposits, it seems evident that during the Bronze Age also those ore deposits were used, in the surroundings of which no traces of prehistoric mining have been found yet.

Mining

In the course of dismantling activities of historic and modern mining, researches documented prehistoric mining sites – labelled as " Heidengruben " or " Alte Gruben ". The designation "Heidengrube" ("pagan pit") suggests that historical miners were assuming a prehistoric time-framing for these mining relics. Detailed reports by prehistorians and depositors on these sites have only been available since the middle of the 19th century. It can be assumed that miners had already encountered the remnants of the prehistoric mining in earlier times. One should keep in mind, however, that such discoveries were not systematically recorded in the late Middle Ages and Early Modern Times. Furthermore, no relevant research has been carried out on mine reports and maps from this period.

Since the rock stability of the Wildschönau slate is relatively low and artificial cavities can thus not withstand the mountain pressure for very long, the portals and galleries collapsed after the abandonment of the historical or modern mining. Today, there are no more accessible underground sites, so the reports of Matthäus Much, Alexander Schernthanner and Franz Pošepný are important sources of information for prehistoric underground mining.

The low stability of the host rock suggests that the Bronze Age galleries had to be reinforced much more than in other prehistoric mining regions in the western Greywacke zone. Interestingly, Matthäus Much compared the severely broken old mines in the Kelchalm district with the "Heidengebirge" of the salt mines of Hallstatt and Dürrnberg and described the situation as a *„wirre Masse von Trümmergestein, Schlamm und Holzstücken“ "tangled mass of debris, mud and wood pieces"* (Much, 1879).

Even Pošepný, who traveled to the mines of the Habsburgian Monarchy in Siebenbürgen, Bohemia and the Alps, emphasized that the study of the Kitzbühel mining industry was made considerably more difficult by the brittleness of the rock as well as by the necessary dense timbering of the galleries (Pošepný, 1880). The great dimension of this fact results from the compilation of the gallery system in the Schattberg- and Sinnwell district to the west of Kitzbühel. In 1805 out of a total of 25.506 kilometers, 58% had been collapsed, 35% were timbered, and only 7% of the galleries were located in solid rock without timbering.

Findings of Underground Mining

The only traces of prehistoric underground mining that were investigated and described by scientists so far were found in the Schattberg and Kelchalm district in the middle of the 19th century. In 1843, a prehistoric mining site was discovered in the Schattberg, southwest of Kitzbühel. It included fresh-looking timbers, wedges of oak, a wooden shovel, a "leather apron" as well as stone tools for ore-processing, which Much compared with those found at the Mitterberg district (Much, 1879). In the course of the following years, further prehistoric mining sites were discovered near these pits.

In the Kelchalm district, "old mines" filled with water were discovered above the Danieli gallery, which experienced a water eruption in 1855 (Much, 1879; 1902; Pošepný, 1880). These pits included a variety of prehistoric finds, including burnt tapers, a bronze needle and even a wooden box construction (Much, 1879; Pošepný, 1880; Schernthanner, 1893). The keeper Anton Duxneuner had seen the box, which was made from spruce boards, and reported the following:

„Es standen drei Säulen in einer Reihe, und zwischen je zweien davon eine viereckige Holzkiste, über der eine Stange lag. Nebst offenbaren Trogfragmenten fanden sich auch aus Haselstauden angefertigte Siebe, so dass man die Existenz einer Siebsetz-Vorrichtung annehmen zu müssen glaubte, wobei die in die Kisten eingesenkten Siebe auf der oben befindlichen Schwungstange aufgehängt gewesen sein mögen.“ (Pošepný, 1880).

Fig. 3: Mating heads for gland pelts from the ore-processing heap 32 of the Kelchalm district - without scale (according to Preuschen & Pittioni, 1937 and Pittioni, 1947, compilation according to Koch Waldner, 2017).

"There were three pillars in a row, and a square wooden box, covered with a pole, was situated between two of the pillars. In addition to the trough fragments, sieves made of hazelnut shrubs were discovered, so that the existence of a sieve device was assumed, whereas the sieves indented into the boxes would have to be suspended from the swing-rod above."

Whether the findings were actually an ore-processing facility, however, cannot be fully confirmed. If the miner's interpretation were actually correct, this facility as well as the stone tools from the Schattberg would represent the only evidence for underground ore-processing of the Bronze Age copper mining in chalcopyrite deposits.

Another miner came across a further unique find in the old mines of the Kelchalm district. It was a broken wooden stick, which at certain intervals had notches and "*enigmatic*" symbols, which the finder interpreted as a probable mining measurement device. As nobody seemed to be interested in this unique discovery, he threw it away, so that today his interpretation cannot be confirmed anymore (Schernthanner, 1893).

On the surface, too, several finds were discovered that served for mining activities underground. Among the material collected during the excavations of Preuschen and Pittioni at the ore-processing heaps, there are leftovers of timber shafts for socketed tools (Fig. 3). The comparison with the shafts for bronze picks from the Mitterberg region demonstrates that the finds of the Kelchalm are of the same type (Koch Waldner, 2017; Thomas, 2018). This underlines the fact that in both mining regions the same miner's tools and comparable mining technologies were used.

Recent research was successful in finding several mining maps of the 19th century Kelchalm district that depict the find spots. Due to the importance of accurate surveying in underground mining, the visual map material provides a precise representation of the network. This enabled the calculation of the depth mining of the old cavity. The pit-plans were adapted to a geo-referenced orthofoto and a terrain laser scan. The distance between the entrance of the Danieli gallery and the site were determined by a vertical map drawing. Finally, the lowest point of the prehistoric mining site, which is situated in a depth of about 160 m, was calculated. The considerable depths point to an equally highly developed underground structure as that in the Pongau, where the deepest prehistoric copper mining in Europe – in the Arthur gallery near Bischofshofen – lies with a depth of more than 200 m (Thomas, 2018).

Processing

Traces of ore-processing were found in the Kelchalm district and on the Götschen near Brixen im Thale, since here the ore-processing heaps are only partially covered by plants and thus clearly visible. Whereas at the Götschen only prospections were carried out, Preuschen and Pittioni were able to gain important insights into prehistoric ore beneficiation technologies through their excavations on the heaps of the Kelchalm district. They are located in the flat slope of the Freibergsattel south of the Laubkogel on approximately 1760 m a.s.l. "Kelchalm" in the narrow sense refers to the area west of this saddle region. The area east of the ridge is called Bachalm. Given that in historical time, the deposit was approached from the Kelchalm, the entire mining quarter was named after it. During the archaeological excavations and prospections of Pittioni and Preuschen, it was possible to differentiate more than 50 heaps (Preuschen & Pittioni, 1937). The many finds and results from the "Scheidehalde 32" are connected with ore beneficiation (picking, sorting ...) – the separation of ore from dead rock. They show the process of prehistoric ore-processing ("chaîne opératoire") in an impressive manner. The latest excavation results emphasize that, at the beginning of prehistoric use, an existing forest stock was cleared in the ridge region (Klaunzer et al., 2010). The clearing of the trees, on the one hand, served to expose the rock, on the other hand the wood could then be used as construction material and fuel. Subsequently, work areas were set up.

The entire ore beneficiation process can be reconstructed on the basis of the finds from the "Scheidehalde 32". The extracted ore, partly still intergrown with dead rock, was first subjected to coarse comminution by the

Fig. 4: Aerial view of the Kelch- and Bachalm (© Land Tirol) with floor plan of the Kelchalm disctrict (after Pošepný 1880). The prehistoric heaps can be seen on both sides of the ridge. In the mine plan, the mined ore bodies are shown in grey and the prehistoric mining pit is marked red (according to Koch Waldner, 2017).

use of stone tools such as "Scheidhämmer" (cobbing hammer) and anvils. Then the ore was sorted out. The dead rock, often larger pieces, was thrown to the heap. This first working step is demonstrated by up to 10 cm chunks of dead rock in the processing heap. In case the ore was heavily grown together with the host rock, grinding stones, which were pulled over large stone blocks, were used for finer processing. With the aid of these ore mills, the ore-bearing rock was reduced to a uniform grain size. Subsequently, in a wet-mechanical working step, the pounded and finely ground material was separated in water due to the different specific gravity of the ore and the dead rock. This process is comparable to gold washing, in which the heavy, rich material accumulates under the lighter, dead material by constant swirling, securing and pivoting. The copper-rich concentrate obtained during the washing was finally separated by means of wooden knife-like tools.

Such knife-shaped instruments of wood, as later described by Georg Agricola (Agricola, 1556), were also found in the ore-processing heap of the Kelchalm (Preuschen & Pittioni, 1937).

Further findings related to the wet-mechanical beneficiation are the ponds that were documented on the Kelchalm, two wooden troughs (Fig. 6) and several wooden channels and ground channels (Preuschen & Pittioni, 1954). Wooden channels were used to transport clean water to the wet processing plants. Afterwards, the dirty water was derived with simple ground channels. The troughs measured about 175 x 80 cm at the time of their discovery. Similar to the box construction for the wet processing of ore from the Troiboden near Mühlbach (Stöllner et al., 2012; Stöllner, this volume), the troughs include a transversely running wooden rod. This indicates that the troughs were used for a similar wet processing technique as the boxes in the Mitterberg Region. A box construction made of boards in the area of "Scheidehalde 32" was interpreted as waste pit by Preuschen and Pittioni. According to today's research, it seems more obvious that this construction also represented a wet

Fig. 5: Prehistoric heaps on the Bachalm in the Kelchalm district (photo: T. Koch Waldner).

Fig. 6: Trough for the wet processing of ore from "Scheidehalde 32" in the Kelchalm district (photo: A. Blaickner).

processing facility (Koch Waldner & Klaunzer, 2015). In addition to the well-preserved wooden artifacts, such as posts, wedges, roof shingles, cooking utensils, and tally sticks ("Kerbhölzer"), which may indicate an early counting system, many ceramic fragments, animal bones and some bronze finds were discovered (Klaunzer, 2008).

One particular foundation stands out (No. 61 according to E. Preuschen and R. Pittioni) and is interpreted as a substructure for a building (Preuschen & Pittioni, 1954). This finding as well as the mentioned shingles and a wooden whisk (Pittioni, 1947) for butter production are the most important indications for a settlement in this mining area.

Smelting

The extracted ore was roasted on cobbled roasting beds and smelted in shaft furnaces. Since Pittioni mainly carried out prospecting in the municipality of Jochberg, the area is known for its prehistoric smelting sites. The frequent occurrence of these sites in and around Jochberg is not due to spatial organizational structures of the prehistoric mining system, but can be traced back to intensive archaeological prospections and the attention of the inhabitants in this area. A similar density of smelting sites could therefore

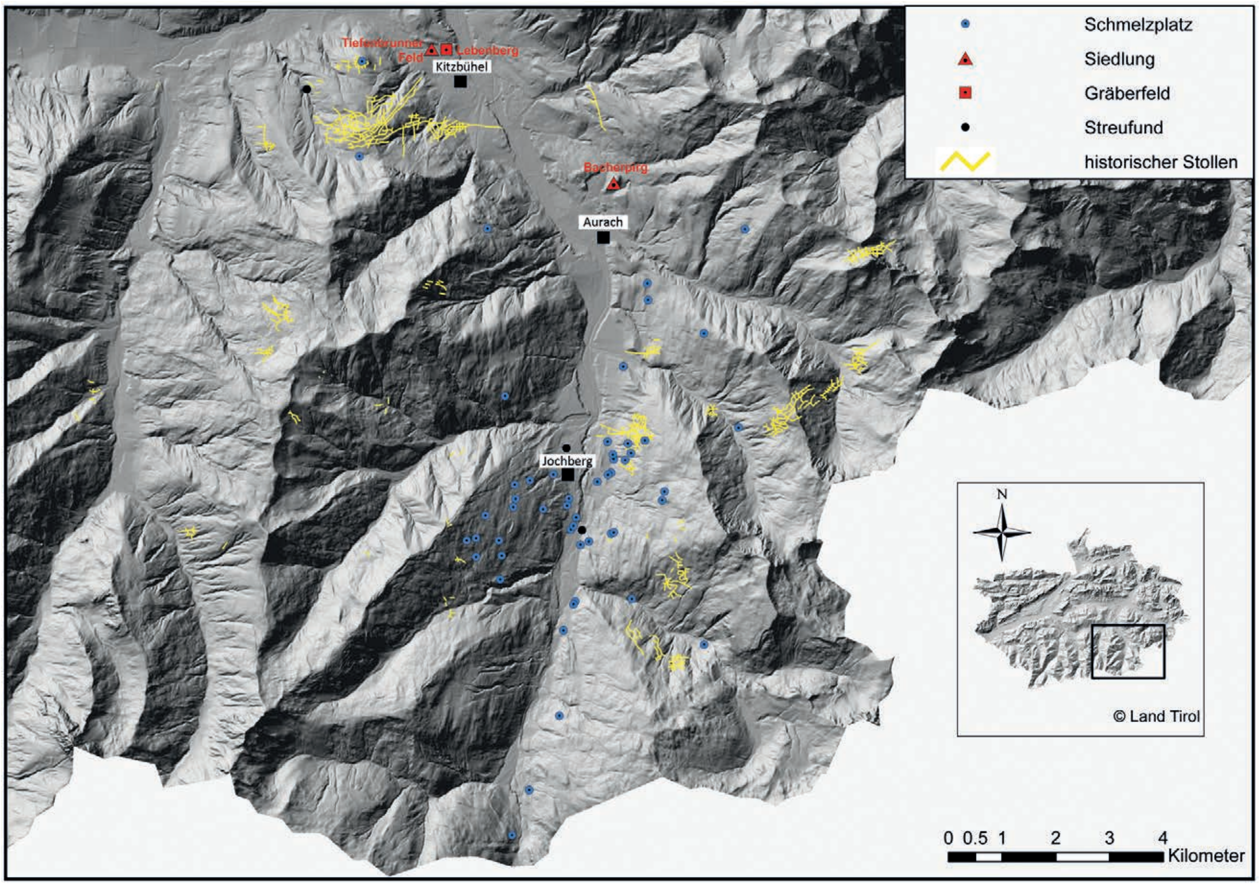

Fig. 7: Distribution of prehistoric smelting sites (according to Koch Waldner, 2017, produced by R. Skomorowski & T. Koch Waldner).

also be assumed for the municipalities of Kitzbühel and Aurach. In addition, it has to be taken into account that numerous construction measures, particularly in Kitzbühel, could be responsible for the destruction of many of the sites since the Middle Ages. This is also why their actual distribution cannot entirely be reproduced. Recent research has attempted to locate the sites mentioned by Pittioni. During research, several previously unknown smelting sites were discovered. A new coding was used to obtain a structured reference character. The smelting sites (SP) are provided with an additional abbreviation for the found area (for example, WH for Wurzhöhe, SK for Schützenkogel).

Smelting facilities

Pittioni carried out several excavations on slag sites from the 1950s to the 1970s. However, no well-preserved furnace structures could be discovered and documented. Prehistoric furnaces and roasting beds were first excavated and published at the WH/SP 1 (Hechenberg) site in the 1990s in the area of the Wurzhöhe (Goldenberg, 2004). Promising surface findings (slag and furnace fracture) as well as the results of a magnetic field measurement at this smelting place (1305 m a.s.l.) resulted in two excavation campaigns. Four smelting furnaces, including a double furnace and a two-phase roasting bed, were documented.

In the summer of 2012 another smelting facility was excavated and documented on the smelting site WH/SP 5 (Koch Waldner et al., 2013b; Koch Waldner, 2017). The site (1115 meters above sea level) was first mentioned by Pittioni in 1968 as SP 27. The remains of furnaces and a roasting bed were located along a terrain edge by means of surface finds, core drillings and magnetic field measurements. A double furnace and a part of the accompanying roasting bed were uncovered.

The roasting bed was made up of a pavement of flat stone slabs in a clay layer and larger boundary stones. The double furnace (Fig. 8) was located downhill, 1.20 m away from the roasting bed edge. The furnace walls were placed in a terrain edge, the interior was 50 cm wide and about 80-100 cm long. On the back of the furnaces were two pits filled with slag cakes and two further pits filled with stones. They probably served to reinforce the walls.

Of the hitherto investigated smelting sites, this is the only one where exclusively slag cakes (fragments), but no plate slag or slag-sand are present. These technological differences could be explained by the age of this site. On the basis of ^{14}C-data the WH/SP 5 site can be dated into the 15th century BC and thus representing the oldest explored smelting site in the region.

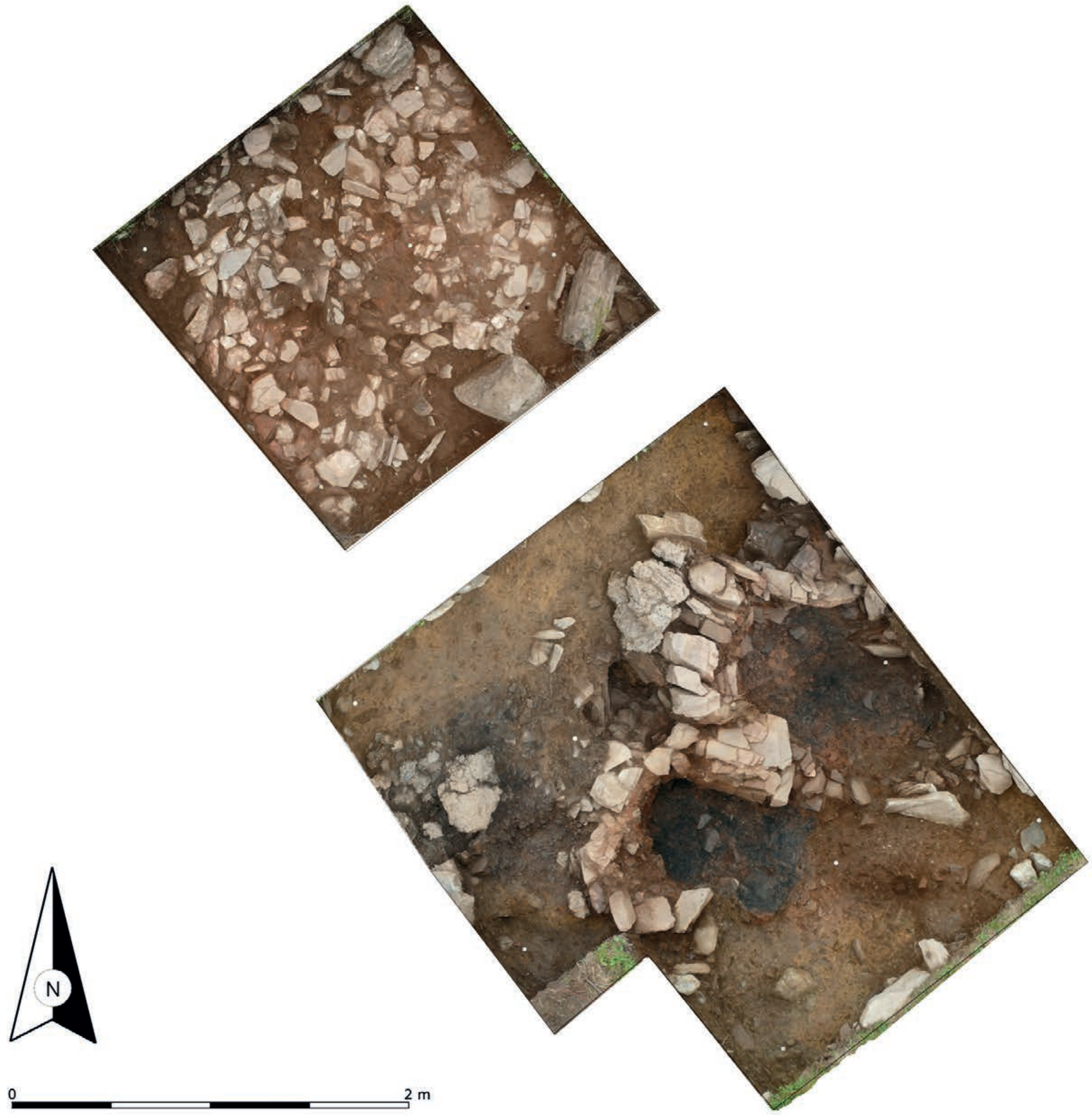

Fig. 8: Roasting bed and the double furnace with slag deposits behind of the furnace on the smelting site WH/SP 5 – photogrammetric plan (after Koch Waldner, 2017, plan: R. Skomorowski & T. Koch Waldner).

After Preuschen and Pittioni carried out initial archaeological excavations in the Kelchalm district's smelting site LK/SP 1 in 1932 (SP 1 according to E. Preuschen and R. Pittioni), the local population continued to work on the site in the 1970s. However, the results were not published. Only after intensive research both the photographic and the graphic documentation of these excavations, were finally found in 2013 (Koch Waldner, 2017). During the second, unpublished excavation, furnaces were uncovered, so that altogether at three sites smelting facilities were excavated.

By means of geomagnetic measurements, it was possible to locate further furnace records at the Wurzhöhe, which should be further investigated in the future.

Slag processing

The slag processing is based on a similar technology as the ore-processing. After a smelting process, copper was still bound in the slag. Consequently, the slag was crushed and ground on anvil stones. On the Wagstättalm (WH/SP 4) as well as on other smelting sites with slag sand, several stone tools could be found for such a preparation, including bucking plates (Fig. 11) and hammer stones (Fig. 12) (Koch Waldner et al., 2012b; Koch Waldner, 2017). The crushed and finely ground material was separated by means of a wet mechanical processing. A water source (spring, runlet, swamp etc.) in the vicinity of Bronze Age smelting sites is therefore

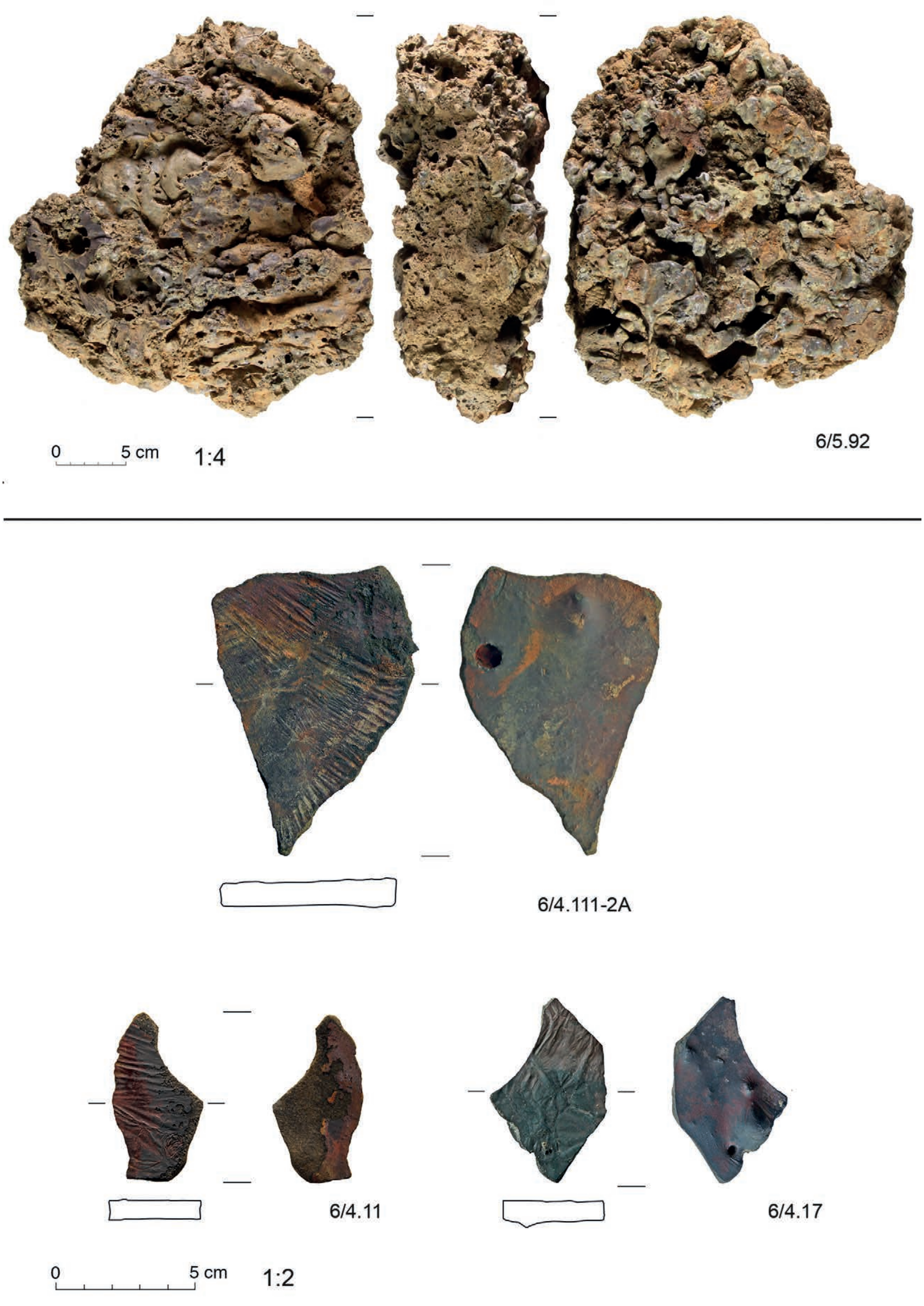

Fig. 9: Slag cake from the smelting site WH/SP 5 and plate slag from the smelting site WH/SP 4 (after Koch Waldner 2017; photos: A. Blaickner & T. Koch Waldner).

an indicative characteristic. The slag sand was finally removed and dumped as a waste product onto the heap. On the smelting site WH/SP 4 (1274 m a.s.l.), remnants of such a washing facility could be documented for the wet mechanical processing of slag (Fig. 10) (Koch Waldner et al., 2012b; Koch Waldner, 2017). These are two parallel, gutter-like channels, which were put in the ground and had wooden boardings on the sides. A plank was found in one of the washing troughs, which originally reinforced one side of the washing plant. The two channels were entirely filled with slag sand. The sand was mixed with waste from woodworking, twigs and spruce or pine needles, which points to the occurrence of woodwork directly at the smelting site. The slag sand heap is located downhill, in close proximity to the washing facility.

Ore-processing at the smelting site

During the prospecting of the past years, quartz pieces with ore residues were found at several smelting sites. At the Wurzhöhe, some cases demonstrate a particularly high proportion of the ore-containing material on the surface of prehistoric slag heap or in the vicinity of the smelting facilities. During a smaller trial excavation in the area of the slag deposit of the smelting site WH/SP 2, researchers detected particularly many quartz pieces with chalcopyrite residues as well as crushed quartz sand deposited directly in the slag sand (Koch Waldner, 2017). A bucking plate with quartz sand was also found at the bottom of a washing plant for slag sand at the smelting site WH/SP 4. At this point, it should be noted that quartz was apparently used as an additive in the smelting process. Since in addition to pure sand also larger quartz pieces with ore residue were found, it can be assumed that at least in some cases ore – at least partly – was processed directly at the smelting site.

This circumstance could be due to the exploitation of smaller deposits near the surface. The ore must have been smelted in close proximity, given that mining, beneficiation and smelting did not need to be spatially separated.

Different spatial organisation of the chaîne opératoire at large and small ore deposits

While numerous smelting sites are located close to the small deposits at the Wurzhöhe near Jochberg, processing heaps have not been found there yet. Bearing this in mind it is striking that only one smelting site was discovered in close proximity to the large deposit and the extensive prehistoric ore-processing heaps in the Kelchalm district near Aurach. This particular situation suggests that the single activities of the chaîne opératoire – mining, processing and smelting – were separated at large deposits with great depth while there was no need for a spatial separation of mining and smelting works at small deposits close to the surface. One reason of the different organization was certainly the high consumption of wood especially as fuel for the smelting works and for the stabilization of the underground mines. As mentioned before, because of the very brittle host rock the mines in the region of Kitzbühel had to be timbered much tighter than in most of the other historic mining regions in the former Austro-Hungarian

Fig. 10: Remains of a washing plant for the wet processing of slag sand at the smelting site WH/SP 4 (photo: T. Koch Waldner).

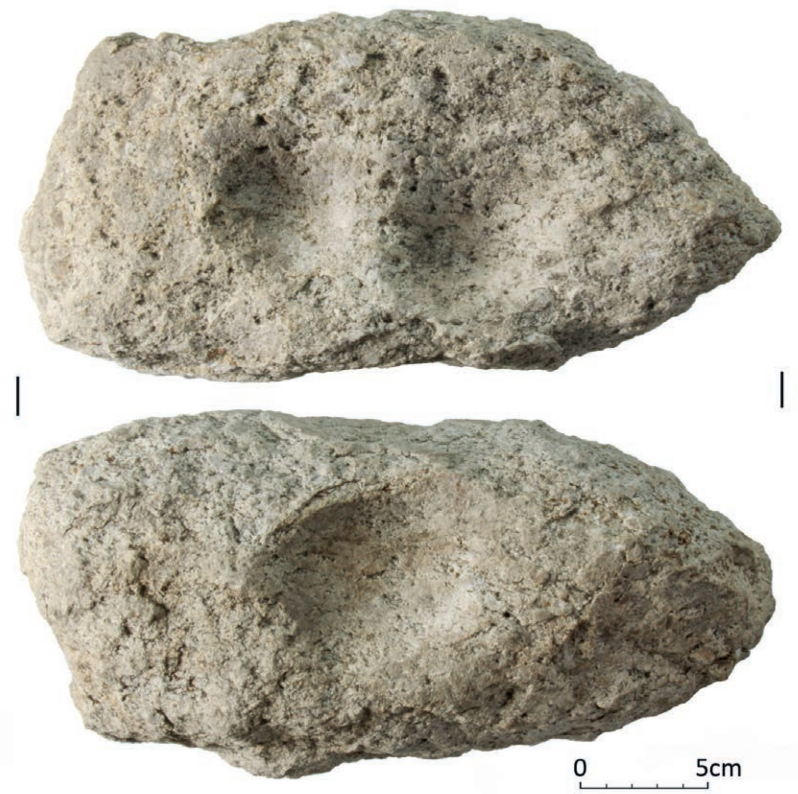

Fig. 11 & 12: Bucking plate and hammer stone from the smelting site WH/SP 4 on the Wagstättalm (after Koch Waldner 2017; photos: A. Blaickner & T. Koch Waldner).

Empire. Therefore it has to be considered that the consumption of wood just for the underground mining work was also very high in prehistoric times.

Small scale mining works did not over-exploit the scarce resources like the extensive mining works at the large deposit in the Kelchalm district. According to this model, also the absence of large mining traces at the Wurzhöhe could be explained.

Dating

In order to determine the duration of prehistoric mining in the Kitzbühel area, a total of nine smelting sites were dated by scientific methods in the framework of the author's research project since 2011 (Koch Waldner, 2017). Previously, Gert Goldenberg already published radiocarbon dates from the smelting site WH/SP 1 (Goldenberg, 2004) as well as dendrochronological dating of several woods from the dumps of the Kelchalm district (Pichler et al., 2009). Due to the dating results, one can suggest an initial phase of the mining industry in the middle Bronze Age or the 15th century BC. The mining industry was on its height in the early phase of the Late Bronze Age. Several smelting sites near Jochberg and the excavation sites in the Kelchalm district date to the first half of the 13th century BC.

This dating approach is confirmed by palynological investigations in bogs as well as the archaeological findings from the southern Leuken Valley and the excavation results of the Bronze Age burial ground "Lebenberg" in Kitzbühel. The partially excavated cemetery dates from the early (Bz D1) to the middle Urnfield period (Ha B1) or from the outgoing 14th to the late 11th century BC (Scheiber, 2011).

In summary, it can be argued that the majority of archaeological finds are from the Late Bronze Age and belong to the Urnfield culture. The oldest known finds, however, date in the transition period of the Early to the Middle Bronze Age. From later periods only a small number of finds is known, primarily from the early Iron Age. The absolute dating of archaeological sites connected to prehistoric mining also reflect a similar picture of the temporal development for the mining and metallurgical industry. This points to a link between the mining traces and those findings which are not directly attributable to the mining industry. The results from pollen analyses confirm the theory that the onset or the increase of archaeological finds is associated with Middle and Late Bronze Age mining. The first occurrence of grain pollen (Viehweider, 2015) during the 14th/13th century BC indicates the intensification of agricultural activities and suggests that the southern Leuken Valley was populated all year round for the first time by those people who were engaged in the mining industry.

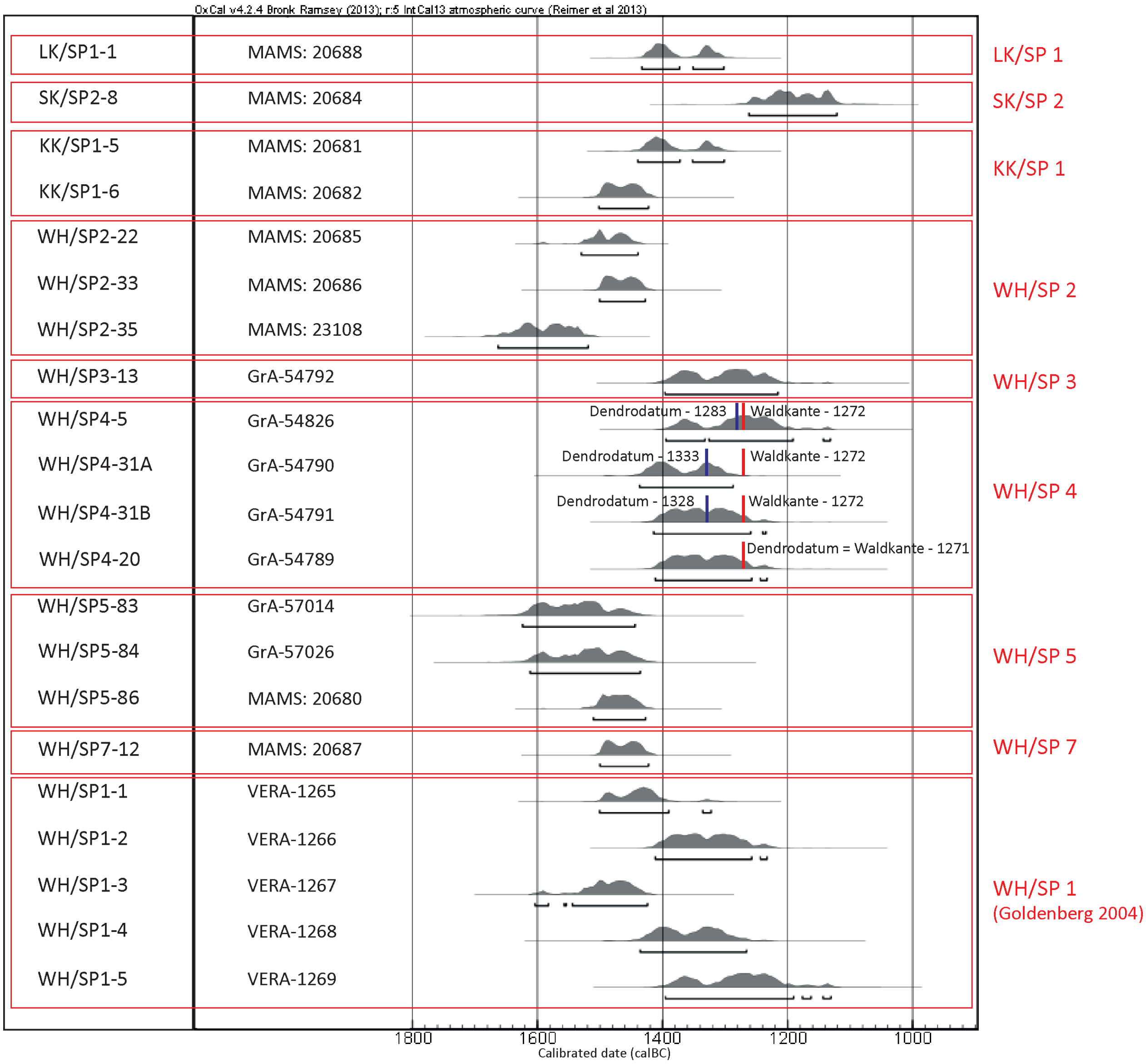

Fig. 13: Multiplot of ^{14}C-samples from different smelting sites near Jochberg and Aruach, as well as the dendrochronological data from the site WH/SP 4 (after Koch Waldner, 2017).

Acknowledgements

I would like to thank the Austrian Academy of Sciences, the Institute of Archaeology and the Deanship of the Philosophical-Historical Faculty of the University of Innsbruck for the support. Special thanks for the support during the fieldwork and research go to Roman Skomorowski.

Note

1 I would like to cordially thank Albert Schedl of the Geologische Bundesanstalt for important information and explanations on the deposits and geological conditions.

Bibliography

Agricola, G., 1556. De Re Metallica. – Zwölf Bücher vom Berg- und Hüttenwesen 2, Wiesbaden 2003.

Goldenberg, G., 2004. Ein Verhüttungsplatz der mittleren Bronzezeit bei Jochberg (Nordtirol). In: *Alpenkupfer – Rame delle Alpi.* Der Anschnitt, Beiheft 17, Bochum, pp.165-176.

Heinisch, H., Pestal, G. & Reitner, J.M. 2015. *Erläuterungen zu Blatt 122 Kitzbühel*, Geol. B.-A., Wien.

Klaunzer, M., 2008. *Studien zum spätbronzezeitlichen Kupferbergbau auf der Kelchalm und Bachalm, Bezirk Kitzbühel, Nordtirol.* Unveröff. Diplomarbeit, Innsbruck.

Klaunzer, M., Goldenberg, G. & Staudt, M., 2010. KG Aurach, OG Aurach bei Kitzbühel, PB Kitzbühel. *Fundberichte Österreich* 48, 2009, pp.389-390.

Klaunzer, M. & Staudt, M., 2011. Fundchronik Bronzezeit, KG Buch, OG Buch bei Jenbach, VB Schwaz. *Fundberichte Österreich*, 49, 2010 (2011), 417.

Koch Waldner, T., Staudt, M. & Goldenberg, G., 2012. KG Jochberg, OG Jochberg. *Fundberichte Österreich*, 50, 2011, pp.414-416.

Koch Waldner, T. & Goldenberg G., 2012. Charakterisierung der bronzezeitlichen Bergbaulandschaft in der Region Kitzbühel – Ergebnisse und Ausblick. In: K. Oeggl & V. Schaffer, eds. *Die Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten.* Proceedings zum 6. Milestone-Meeting des SFB HiMAT vom 3.-5.11.2011 in Klausen Südtirol, pp.126-133.

Koch Waldner, T., Skomorowski, R. & Grutsch, C., 2013a. KG Jochberg, OG Jochberg. Prospektionen zum prähistorischen Berg- und Hüttenwesen im Gemeindegebiet von Jochberg. *Fundberichte aus Österreich* 51, 2012, pp.327-328.

Koch Waldner, T., Skomorowski, R. & Grutsch, C., 2013b. KG Jochberg, OG Jochberg. Ausgrabung des prähistorischen Schmelzplatzes WH/SP 5. *Fundberichte aus Österreich* 51, 2012, pp.328-329.

Koch Waldner, T. 2013. Prehistoric copper production in the region of Kitzbühel, North Tyrol - mining and smelting. In: P. Anreiter, K. Brandstätter, G. Goldenberg, K. Hanke, W. Leitner, K. Nicolussi, K. Oeggl, E. Pernicka, V. Schaffer, T. Stöllner, G. Tomedi, & P. Tropper, eds., *Mining in European History and its Impact on Environment and Human Societies.* Proceedings for the 2nd Mining in European History Conference of the FZ HiMAT, 7.-10. November 2012. Innsbruck: University Press, pp.73-78.

Koch Waldner T. & Klaunzer M., 2015. Das prähistorische Bergbaugebiet in der Region Kitzbühel. In: Stöllner, Th. & Oeggl K., eds. 2015. *Bergauf Bergab. 10000 Jahre Bergbau in den Ostalpen. Wissenschaftlicher Beiband zur Ausstellung Bochum und Bregenz.* Veröffentlichungen DBM 207, Bochum-Rahden: Deutsches Bergbau-Museum Bochum in Kommission bei Marie Leidorf, pp.165-173.

Koch Waldner, T., 2017. *Charakterisierung einer alpinen bronzezeitlichen Bergbaulandschaft anhand von archäologischen Befunden, Geländeanalysen und überregionalen Vergleichen – Räumliche und zeitliche Struktur des prähistorischen Bergbaus in der Region Kitzbühel.* Unveröff. Dissertation, Innsbruck.

Much, M., 1879. Das vorgeschichtliche Kupferbergwerk auf dem Mitterberge (Salzburg). *Mitteilungen der k. k. Central-Commission Neue Folge* 5, pp.18–36.

Much, M., 1893. *Die Kupferzeit in Europa und ihr Verhältnis zur Kultur der Indogermanen* 2, Jena.

Much, M., 1902. Prähistorischer Bergbau in den Alpen. *Zeitschrift des deutschen und österreichischen Alpenvereins* 33, pp.1-31.

Neuninger, H., Preuschen, E. & Pittioni, R., 1970. Der urzeitliche Kupferbergbau Götschen bei Brixen im Tal, p. B. Kitzbühel, Tirol. *Archaeologia Austriaca* 47, Archiv für vor- und frühgeschichtliche Bergbauforschung 36, pp.19-25.

Pernicka, E. & Lutz, J., 2015. Fahlerz- und Kupferkiesnutzung in der Bronze- und Eisenzeit. In: T. Stöllner & K. Oeggl, eds. 2015. Bergauf Bergab. 10000 Jahre Bergbau in den Ostalpen. Wissenschaftlicher Beiband zur Ausstellung Bochum und Bregenz. Veröffentlichungen DBM 207, Bochum-Rahden: Deutsches Bergbau-Museum Bochum in Kommission bei Marie Leidorf, pp.107-111.

Pichler, T., Goldenberg, G., Klaunzer, M. & Nicolussi, K., 2009. Die Hölzer des bronzezeitlichen Bergbaus auf der Kelchalm bei Kitzbühel. *Archäologisches Korrespondenzblatt* 39, pp.59-75.

Pittioni, R., 1947. Untersuchungen im Bergbaugebiete Kelchalpe bei Kitzbühel, Tirol (2. Bericht). *Mitteilungen der Prähistorischen Kommission* 5, pp.37-99.

Pittioni, R., 1968. Der urzeitliche Kupfererzbergbau im Gebiete um Kitzbühel. In: *Stadtbuch Kitzbühel* 2, Kitzbühel, pp.32-102.

Pittioni, R., 1976. Beiträge zur Kenntnis des urzeitlichen Kupferbergwesens um Jochberg und Kitzbühel, Tirol. *Archaeologia Austriaca* 59/60, 1976, pp.243-264.

Pošepný, F., 1880. Die Erzlagerstätten von Kitzbühel in Tirol und der angrenzenden Theile Salzburgs. *Archiv für Praktische Geologie* 1, Wien, pp.257-438.

Preuschen, E., & Pittioni, R., 1937. Untersuchungen im Bergbaugebiete Kelchalpe bei Kitzbühel, Tirol. 1. *Bericht. Mitteilungen der Prähistorischen Kommission* 3, Wien.

Preuschen, E. & Pittioni, R., 1954. Untersuchungen im Bergbaugebiet Kelchalm bei Kitzbühel, Tirol. 3. Bericht über die Arbeiten 1946-53 zur Urgeschichte des Kupferbergwesens in Tirol. *Archaeologia Austriaca* 15, pp.3-97.

Preuschen, E. & Pittioni, R., 1955. Neue Beiträge zu Topographie des urzeitlichen Bergbaues auf Kupfererz in den österreichischen Alpen. Archaeologia Austriaca 18, pp.45-79.

Scheiber, E. M., 2011. *Das spätbronzezeitliche Gräberfeld am Lebenberg bei Kitzbühel*, Tirol. Unveröff. Diplomarbeit, Innsbruck.

Schernthanner, A., 1893. Beschreibung einiger prähistorischer Ausgrabungen in Tirol. *Mitteilungen der Anthropologischen Gesellschaft Neue Folge* 13, pp.59-62.

Stöllner, Th., 2009. Prähistorische Montanreviere der Ost- und Südalpen. Anmerkungen zu einem Forschungsstand. In: K. Oeggl & M. Prast eds., *Die Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten.* Proceedings 3. Milestone-Meeting SFB HiMAT 2008, Innsbruck: University Press, pp. 37-60.

Stöllner, T., 2015. Die alpinen Kupfererzreviere: Aspekte ihrer zeitlichen, technologischen und wirtschaftlichen Entwicklung im zweiten Jahrtausend vor Christus. In: T. Stöllner & K. Oeggl, eds. 2015. *Bergauf Bergab. 10000 Jahre Bergbau in den Ostalpen. Wissenschaftlicher Beiband zur Ausstellung Bochum und Bregenz*. Veröffentlichungen DBM 207, Bochum-Rahden: Deutsches Bergbau-Museum Bochum in Kommission bei Marie Leidorf, pp.99-105.

Stöllner, Th., Breitenlechner, E., Fritzsch, D., Gontscharov, A., Hanke, K., Kirchner, D., Kovács, K., Moser, M., Nicolussi, K., Oeggl, K., Pichler, T., Pils, R., Prange, M., Thiemeyer, H. & Thomas P., 2012. Ein Nassaufbereitungskasten vom Troiboden. Interdisziplinäre Erforschung des bronzezeitlichen Montanwesens am Mitterberg Land Salzburg, Österreich. *Jahrbuch des RGZM* 57, 2010 (2012), pp.1-32.

Thomas, P., 2018. *Studien zu den bronzezeitlichen Bergbauhölzern im Mitterberger Gebiet.* Forschungen zur Montanlandschaft Mitterberg 1, Der Anschnitt, Beiheft 38, Bochum/ Rahden: Leidorf.

Viehweider B., 2015. *The Impact of Prehistoric and Historic Mining Activities on the Vegetation in the Kitzbühel Region*. Unveröff. Dissertation, Innsbruck.

Author

Thomas Koch Waldner – University of Innsbruck and Deutsches Bergbau-Museum Bochum

Correspondence and material requests should be addressed to: Thomas.Koch-Waldner@bergbaumuseum.de